Numerical Modeling Tools for the Assessment of High-Amperage DC Busbars

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HATCH | Centre of Excellence for Aluminium

About the Presenter

- **André Felipe Schneider**
  - **Consultant | Reduction Technology – HATCH | Centre of Excellence for Aluminium**
  - **Bachelor Mech. Eng. (Federal University of Rio Grande do Sul, Porto Alegre, Brazil, 2001)**
  - **M.Eng. (Federal University of Rio Grande do Sul, Porto Alegre, Brazil, 2006)**
- **Work experience & areas of interest:**
  - **20+ years experience on (physics-based) numerical modeling for the design & assessment of high-amperage DC busbars, including pot-to-pot circuits, linkage busbars, magnetic compensation loops, booster rectifier busbars & bypass bridges**
  - **Design of high-amperage DC bolted connections**
  - **Thermomechanical assessment and design of heavy machinery & lifting equipment**
  - **Magnetohydrodynamics (MHD)**
  - **Reduction cell energy balance**

Introduction

Introduction

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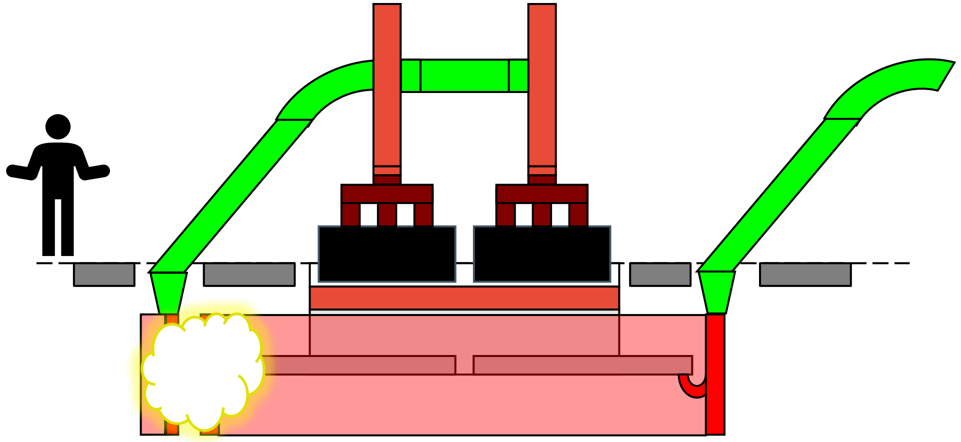
Out of Sight, Out of Mind

- Essentially, busbars provide ***current for the reduction*** of Al_2O_3
- There's a ***lot going on*** at the ***basement***



- Being all ***connected in series***, if ***one*** of these ever ***fails*** …

…. the ***smelter might*** come to a ***halt***

Introduction

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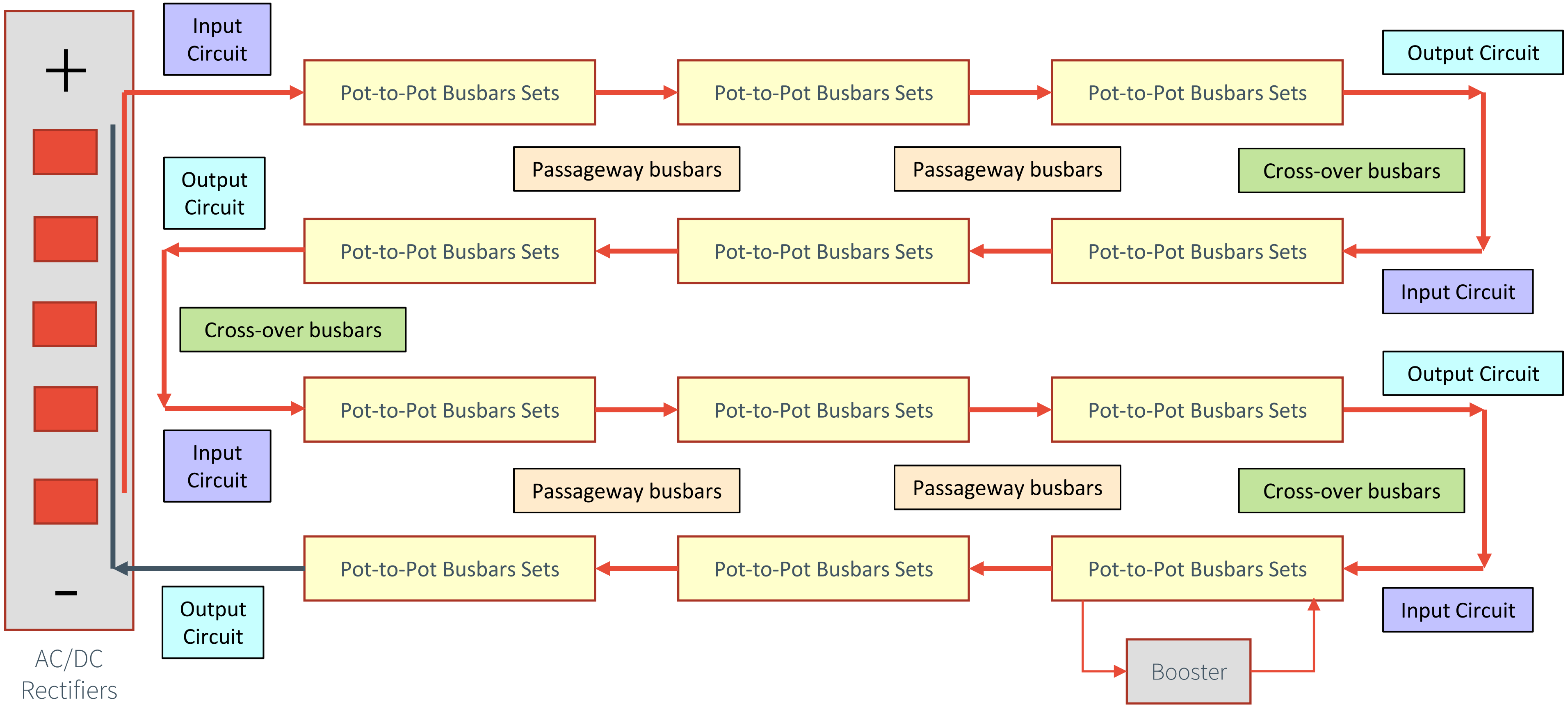
Busbars Nomenclature

- **Pot-to-pot busbars**
- **Linkage busbars:**
  - **Input circuits**
  - **Output circuits**
  - **Passageway busbars**
  - **Crossover busbars**
- **Booster rectifier circuits**

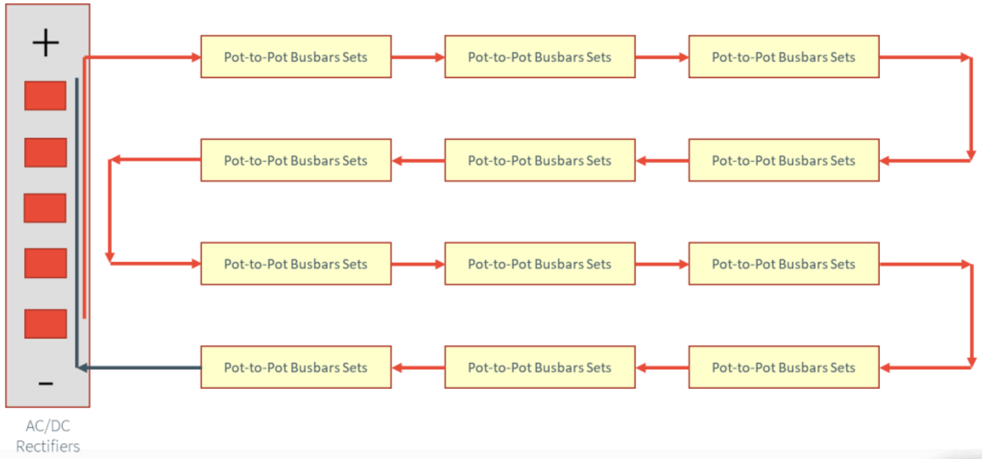


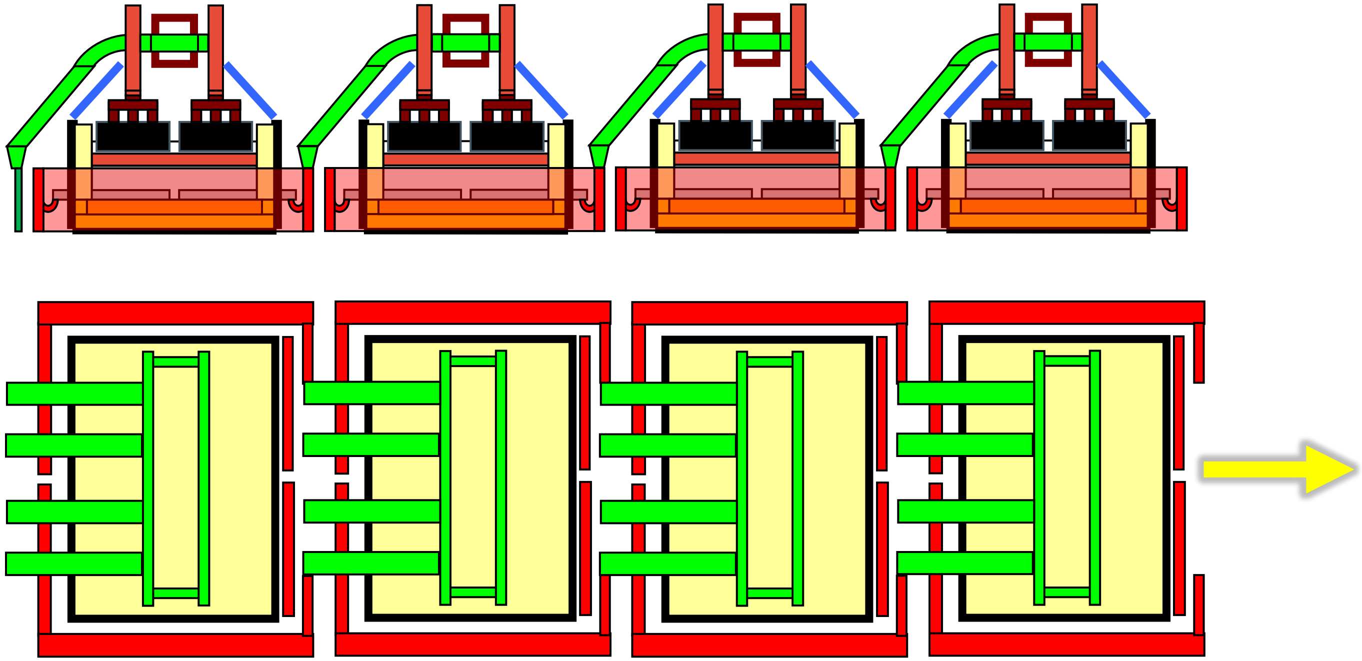
Short Busbars

Introduction

Short Busbars

- ***Pot-to-pot*** **busbars are relatively** ***short*****:**
  - ***3D problem*** **to account for** ***influence*** **of** ***extremities*** **(*****changes*** **in** ***direction*** **and** ***connections*** **to other conductors)**



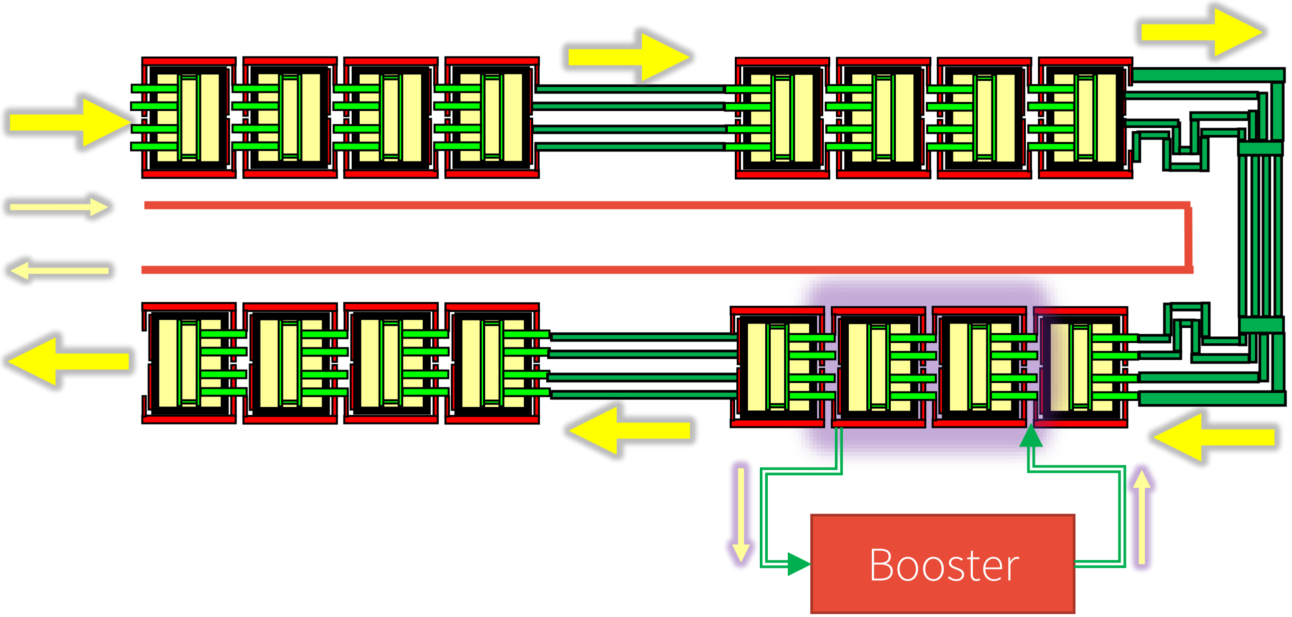


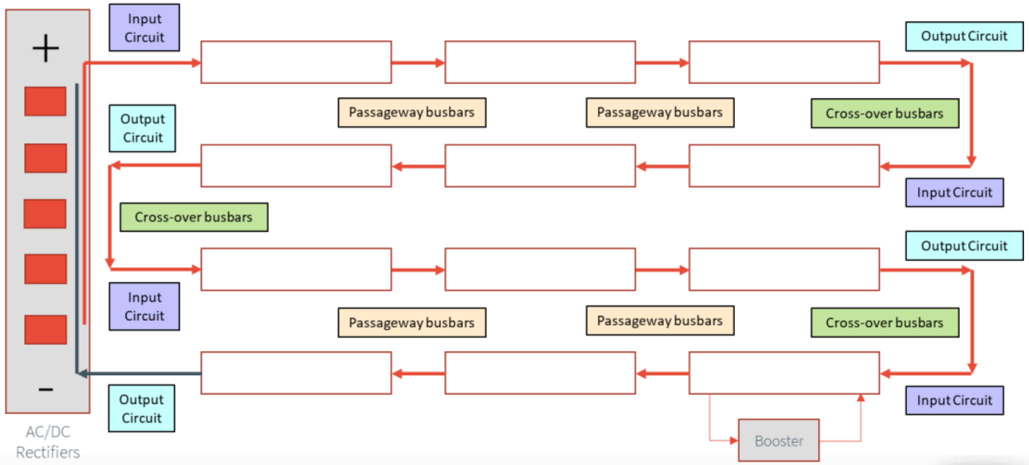
Long Busbars

Introduction

Long Busbars

- ***Linkage*** busbars, ***booster*** circuits & ***compensation*** loops are relatively ***long*** (slender):
  - Simplified as ***2D*** (cross-section wise) or ***1D*** (length wise) ***problems***





Relevant Physics for Busbars Assessment

Relevant Physics for Busbars Assessment

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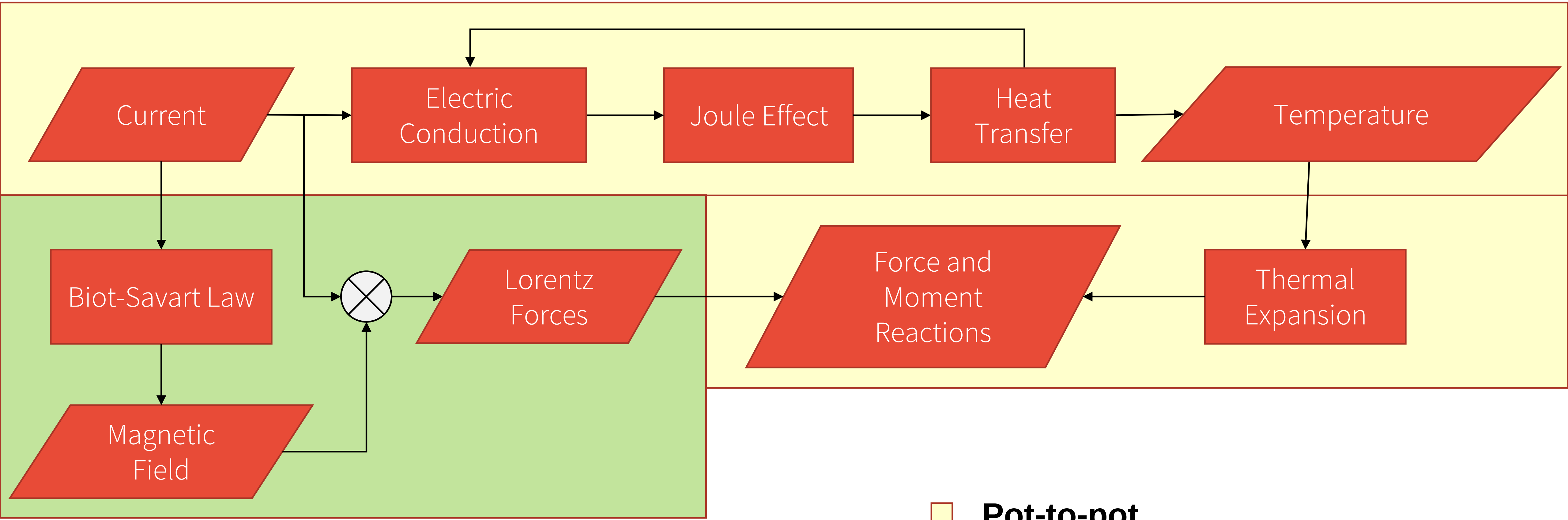
- ***Several physical phenomena interact*** **and must be taken into account**



Pot-to-pot

+ Linkage, booster & compensation

Thermoelectrical Problem

Long Busbars

Thermoelectrical Problem

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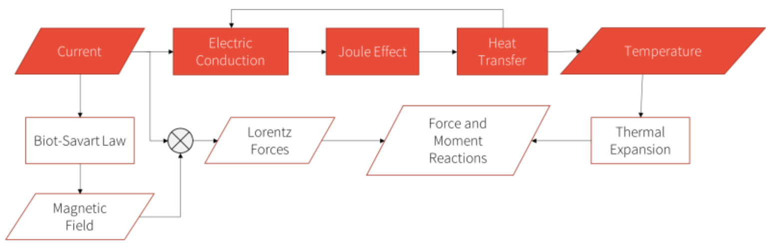
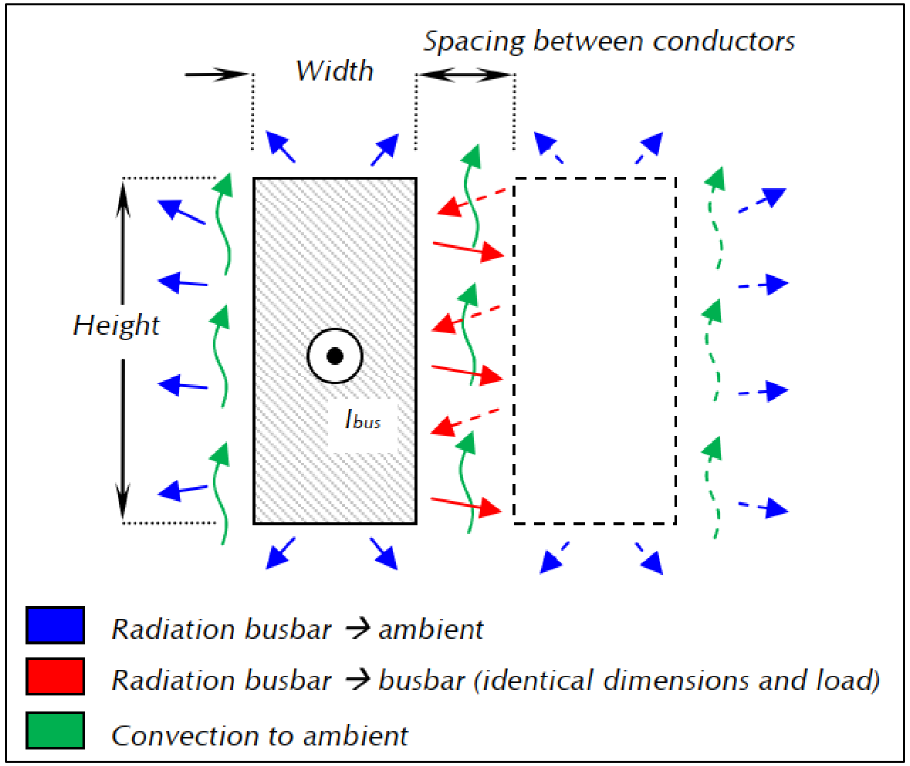
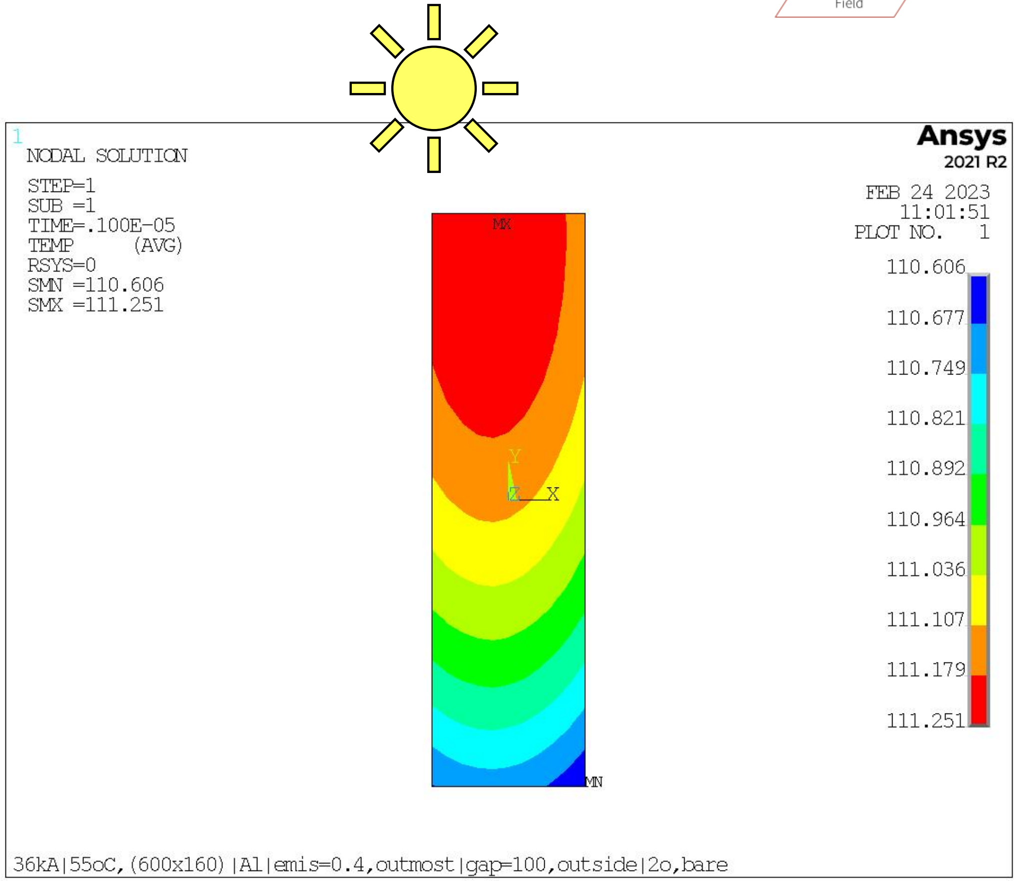
Long busbars



- ***2D TE*** **analysis for** ***long*** **busbars:**
  - **Valid** ***away from*** **busbar** ***extremities***



2D TE approximation for infinitely long busbars

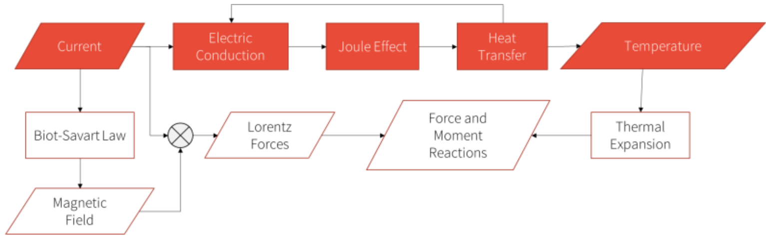


2 busbars, side-by-side:

- **600X160 mm2**
- **36 kA (each)**
- T_{amb} **= 55 °C**
- **Sun load**

Thermoelectrical Problem

Long Busbars | Applications



- ***Application*** **example:**
  - ***400 kA*** **construction** ***bypass bridge*** **for** ***potline extension***

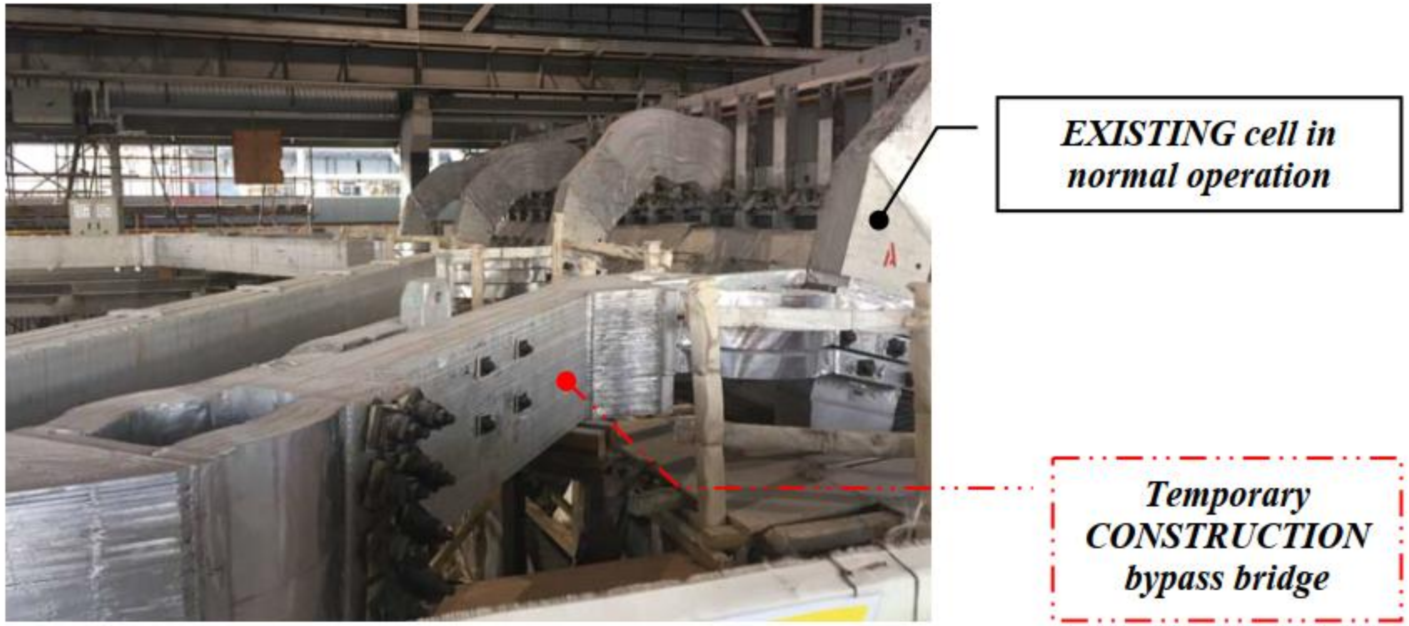


Figure 7. Tie-in of dedicated bypass bridge to existing downstream cell.

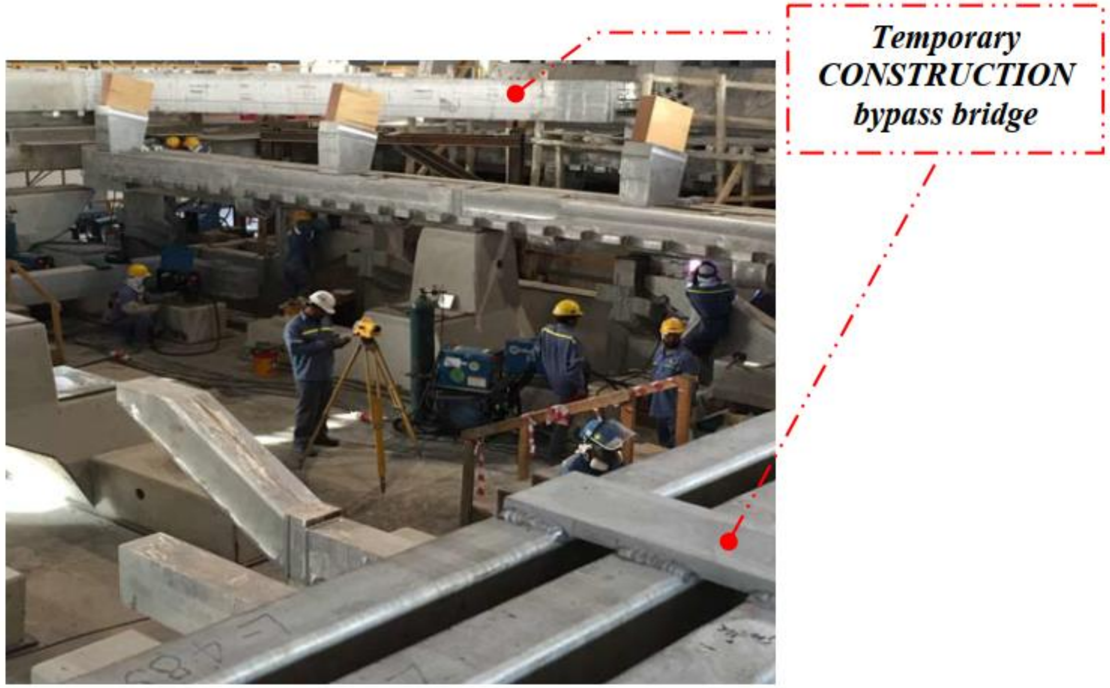
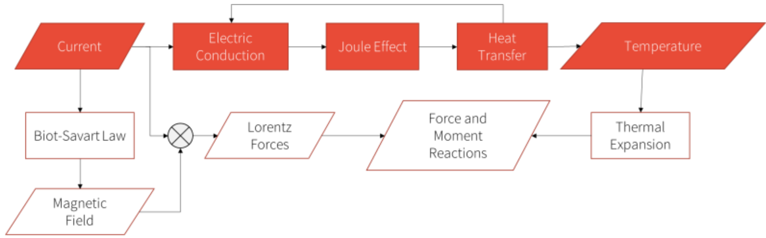


Figure 8. Installation of new busbars and supports.

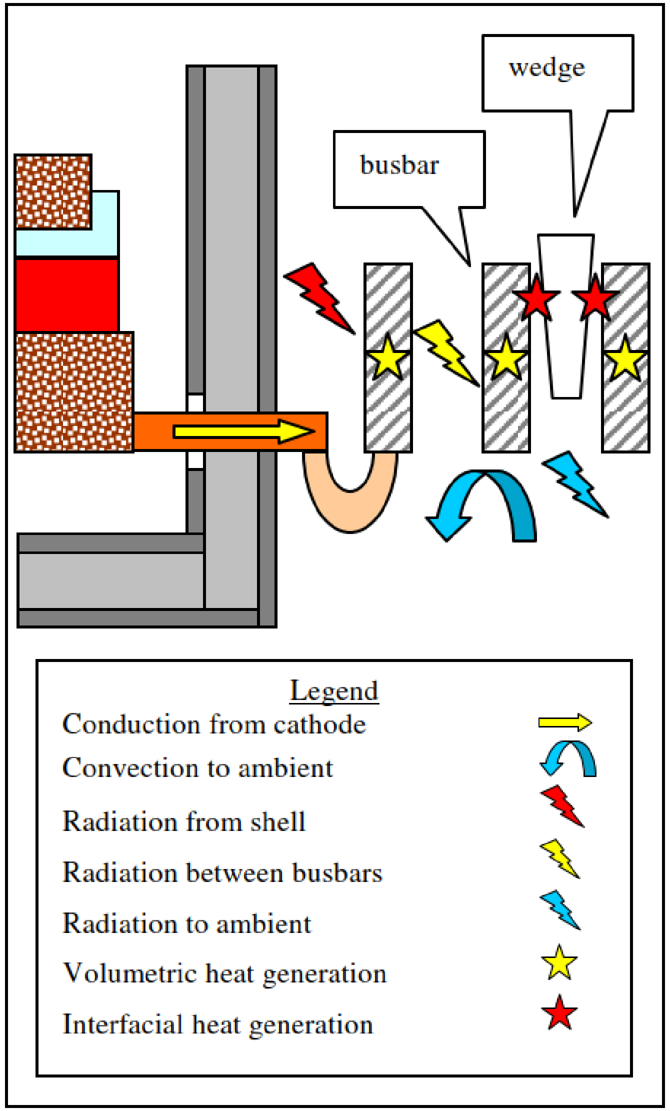
Short Busbars

Thermoelectrical Problem

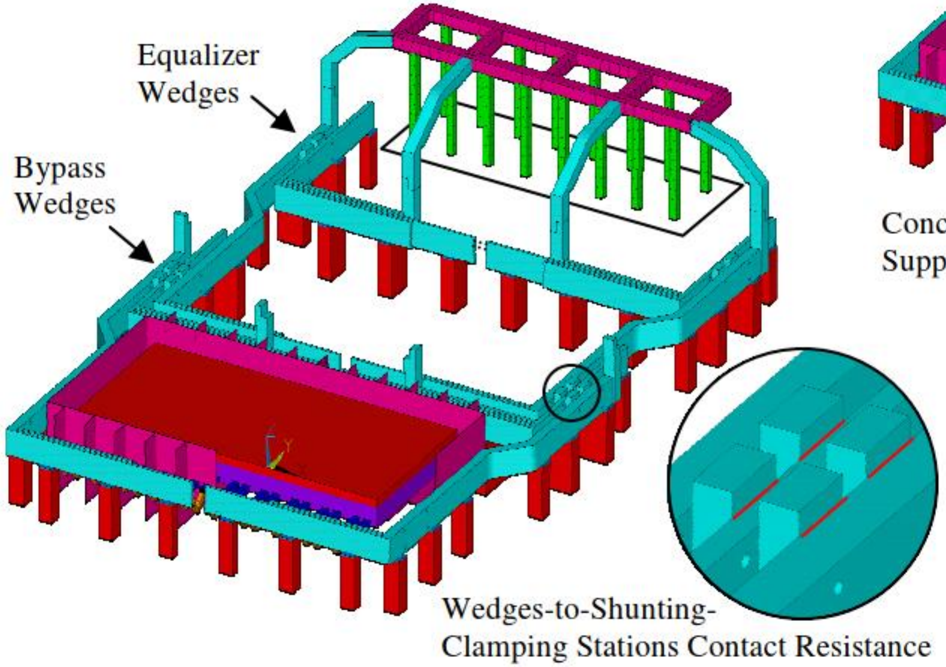
Short Busbars

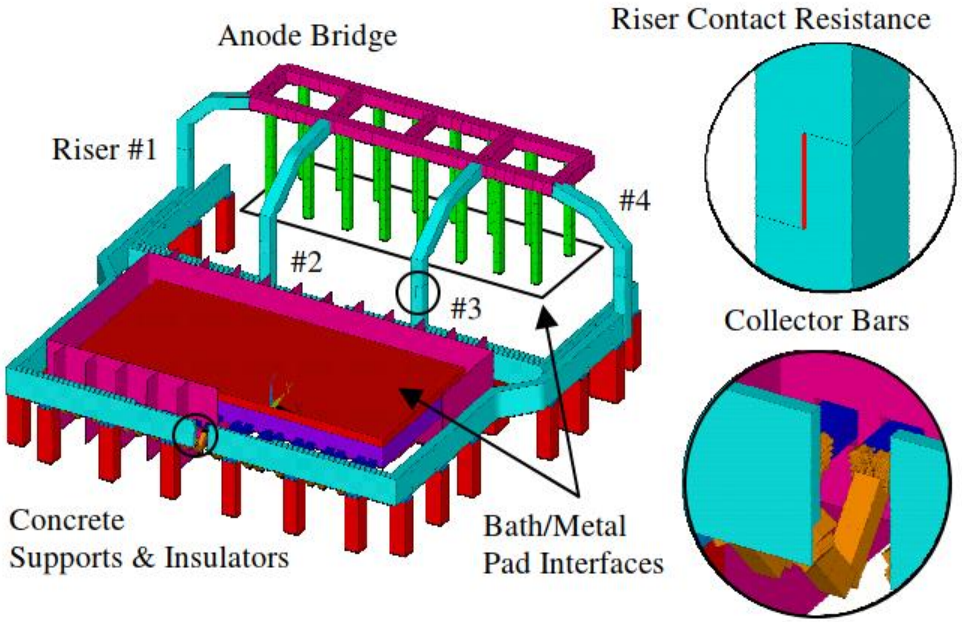


- ***3D TE*** **problem for** ***short*** **busbars:**
  - ***Current distribution*** **depends on the** ***relative resistances*** **of** ***parallel circuits***



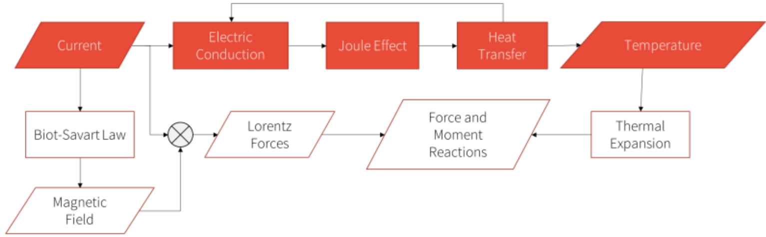
3D TE pot-to-pot multiple bypass



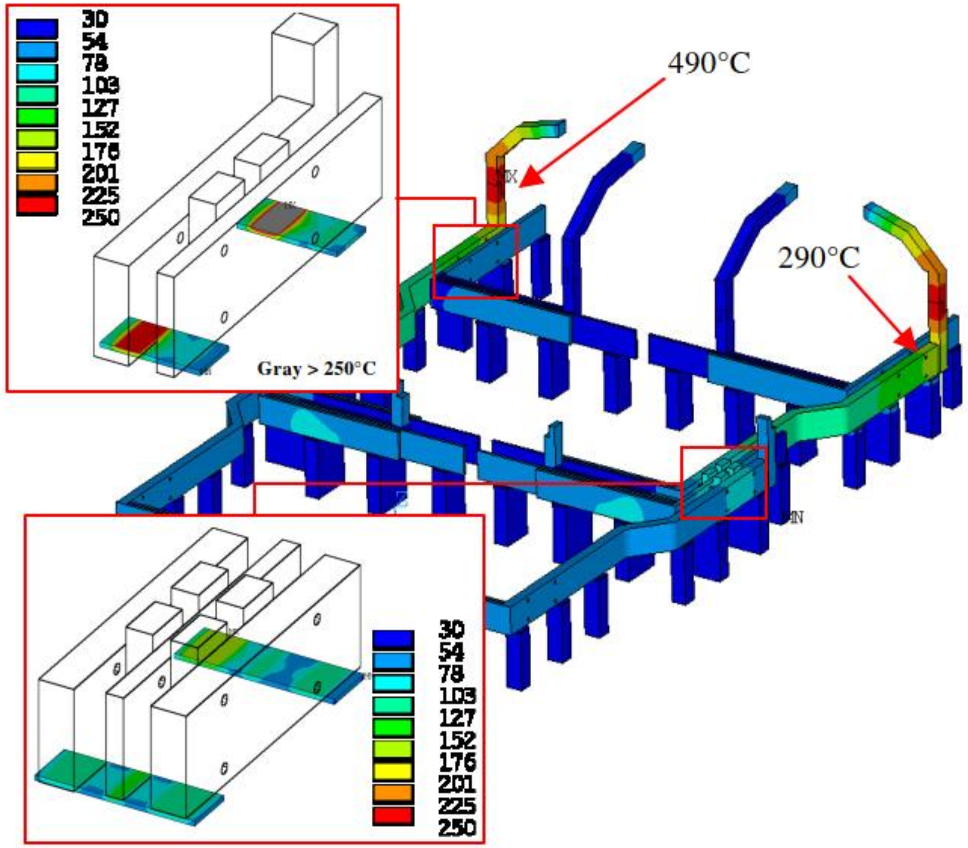


3D TE pot-to-pot normal operation

Thermoelectrical Problem



- ***Application*** **example:**
  - ***Major replacement*** **of pot-to-pot & support** ***insulating material***

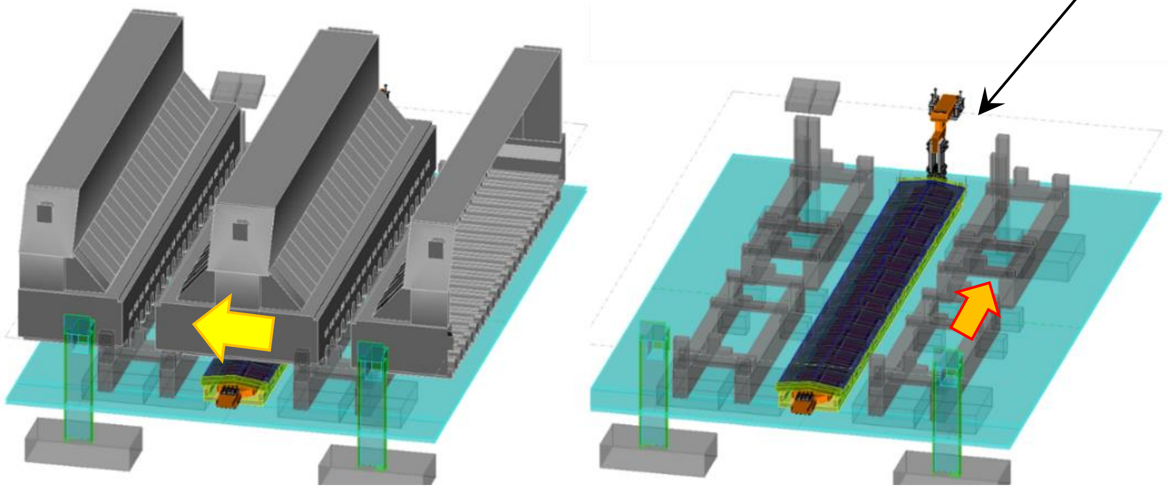


Enclosed Busbars

Thermoelectrical Problem

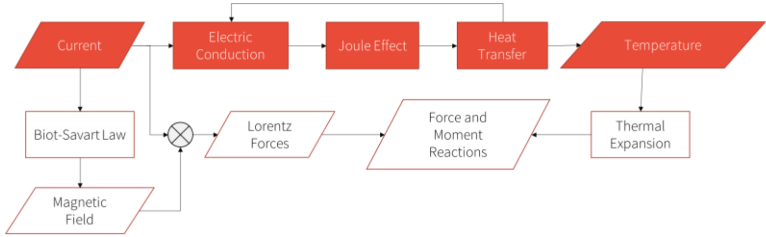
- ***Enclosed busbars*** **(e.g., in a *tunnel* or *culvert*) require *3D thermofluid* analysis (Computational Fluid Dynamics, [CFD])**

New booster + branch & precast concrete culvert

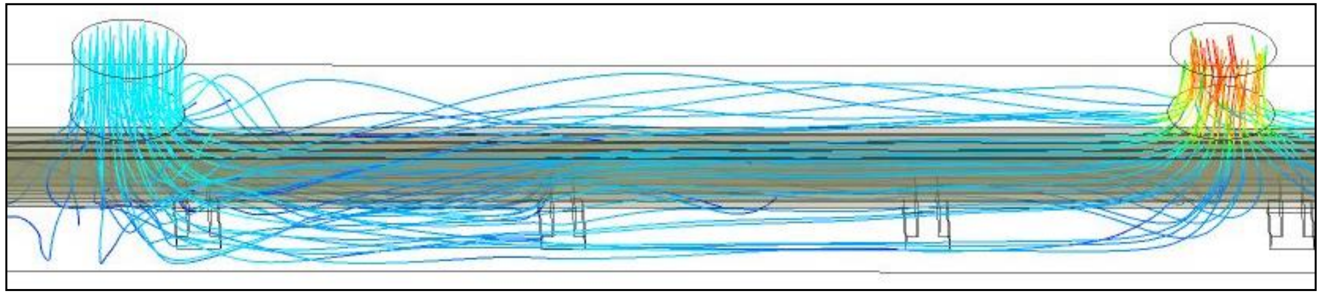


Busbar segment in a confined space

Enclosed Busbars | Applications



- ***Application*** **example:**
  - ***Push-pull*** **ventilation system for *tunnel-enclosed* crossover busbars**

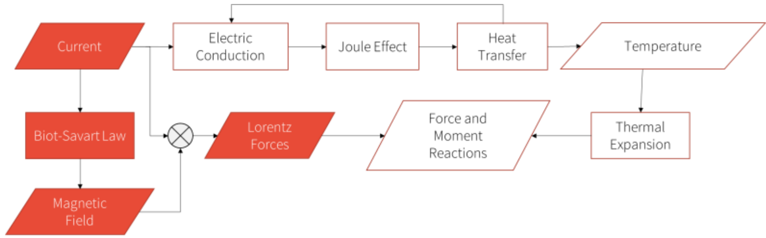


Electromagnetic Problem

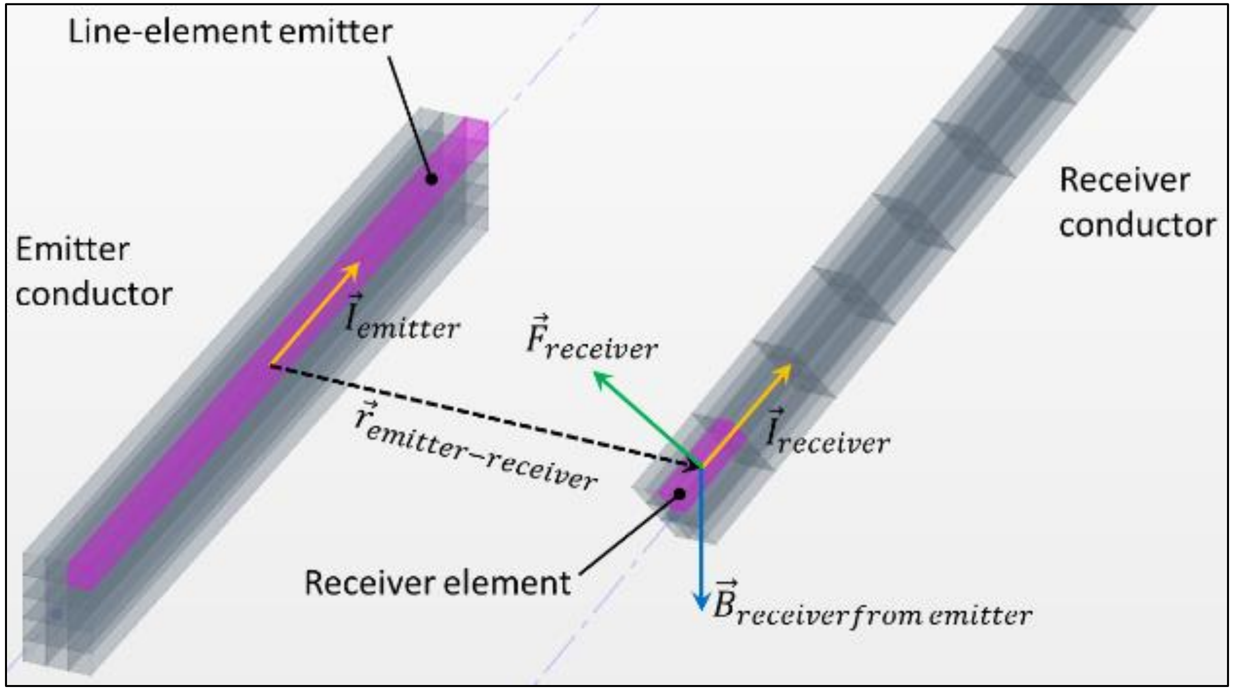
Electromagnetic Problem

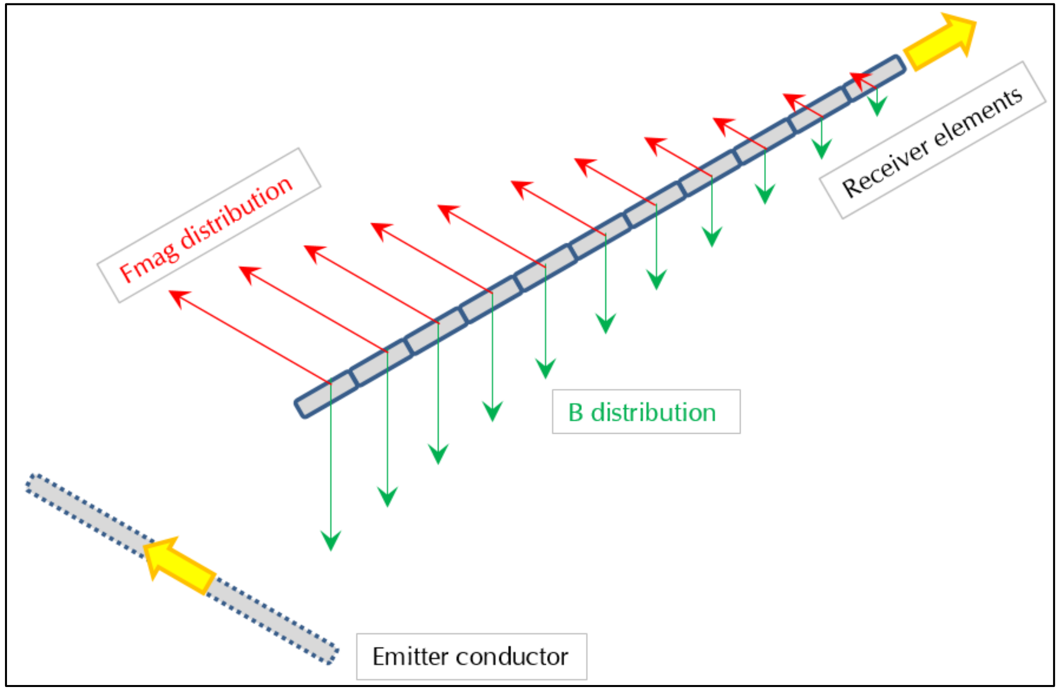
- For busbars ***far removed from ferromagnetic parts*** (e.g., potshell & superstructure), ***magnetic field*** computed by ***Biot-Savart Law*** (BSL):
  - ***Interaction*** with busbars own ***current distribution*** leads to ***Lorentz Forces*** acting on these conductors

Biot-Savart Law & Lorentz Forces



In-house numerical method based on an integral solution of the Biot-Savart Law





Electromagnetic Problem

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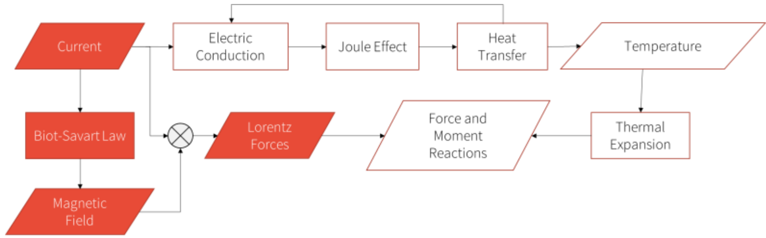
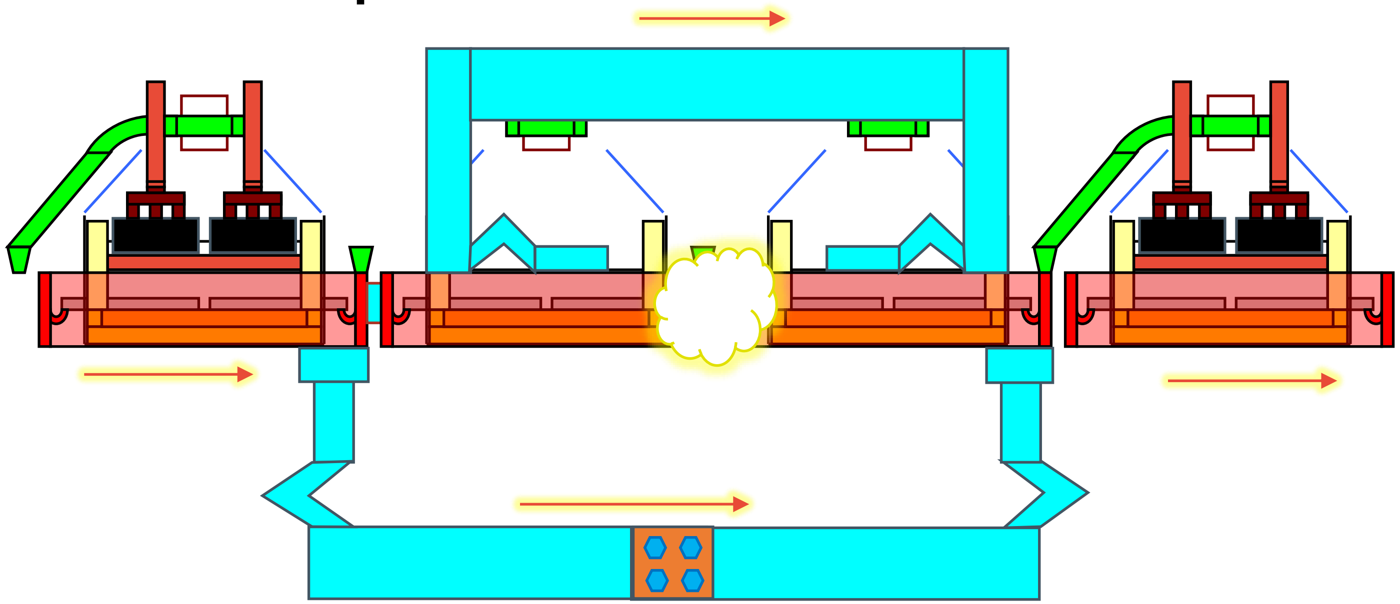
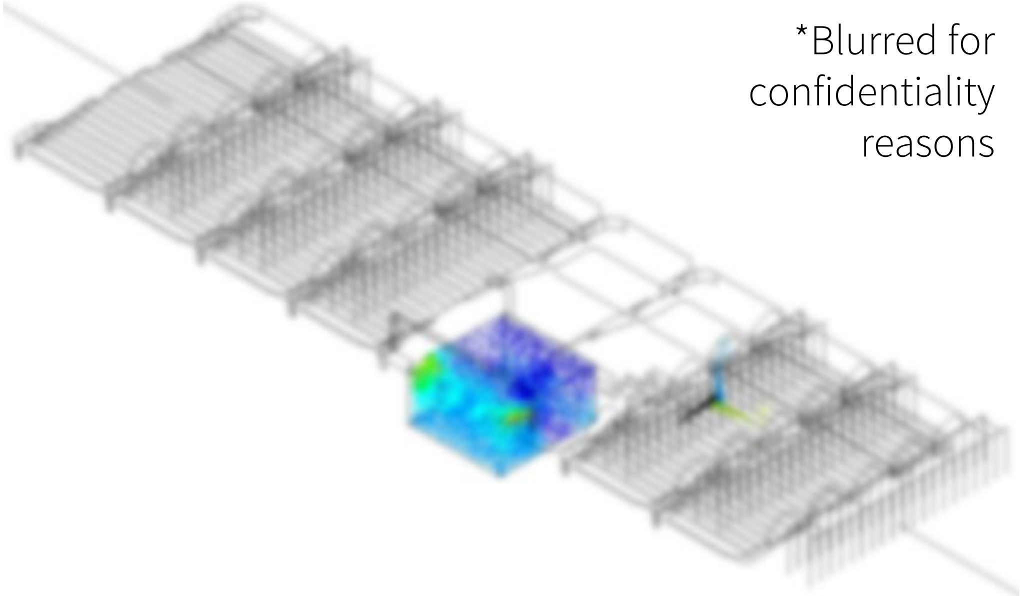
Biot-Savart Law & Lorentz Forces | Applications

- ***Application*** **example:**
  - **Fraction of potline *current rerouted* by repair *bypass bridges* for *reducing magnetic field* intensity in *repair area***
  - ***Weldability assessment* by means of *3D magnetic field* computation**



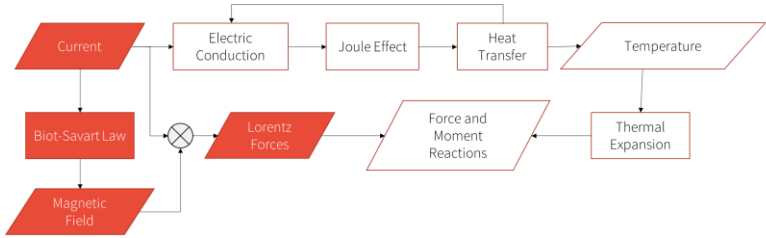




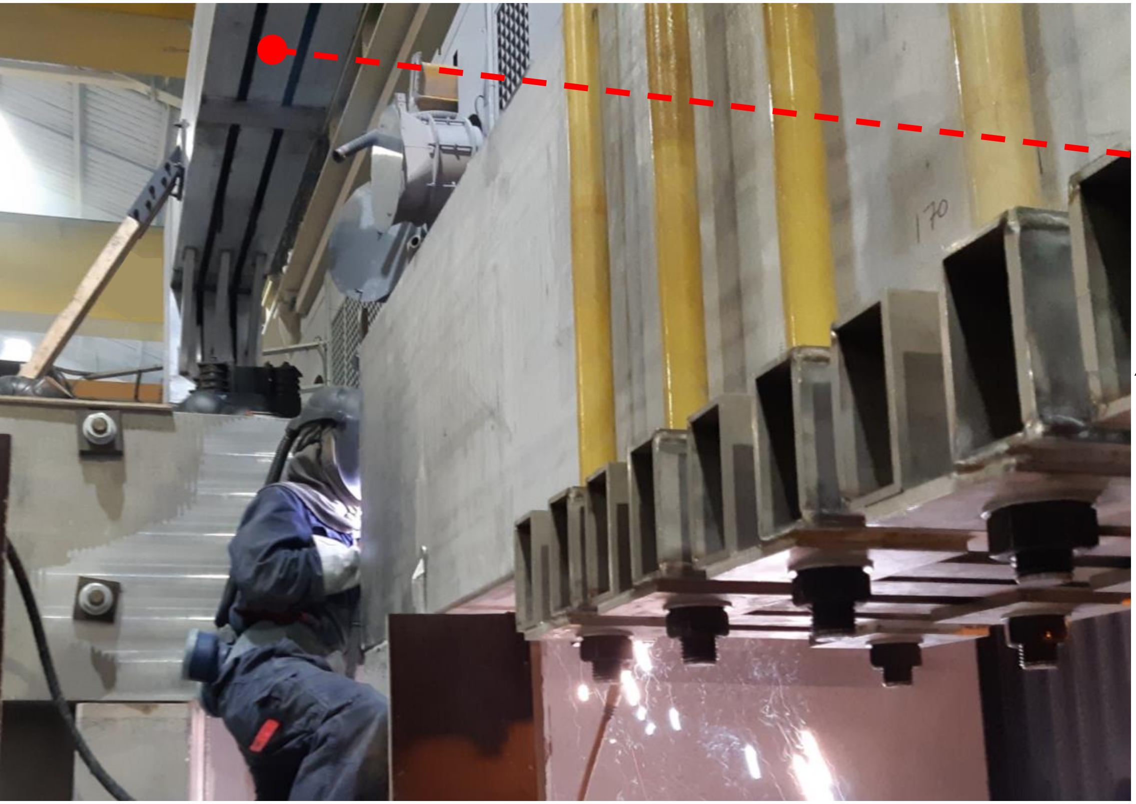
*Blurred for confidentiality reasons

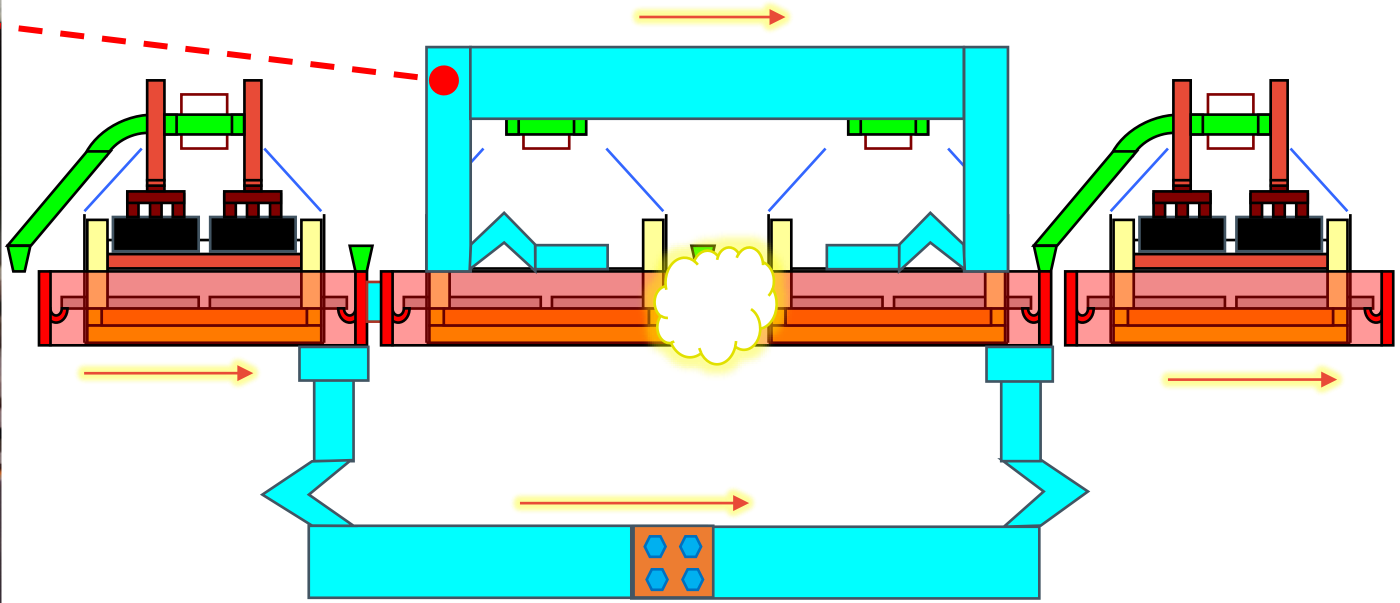
3D magnetic field in repair area*

Electromagnetic Problem



- ***Application*** **example:**
  - ***Major repairs*** **of cathode ring busbars at** ***full potline current*** **by means of** ***electric-arc welding***



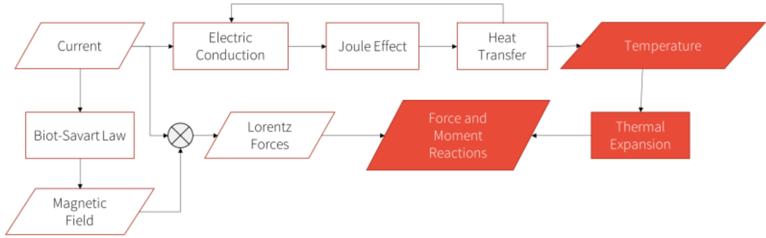


Thermomechanical Problem

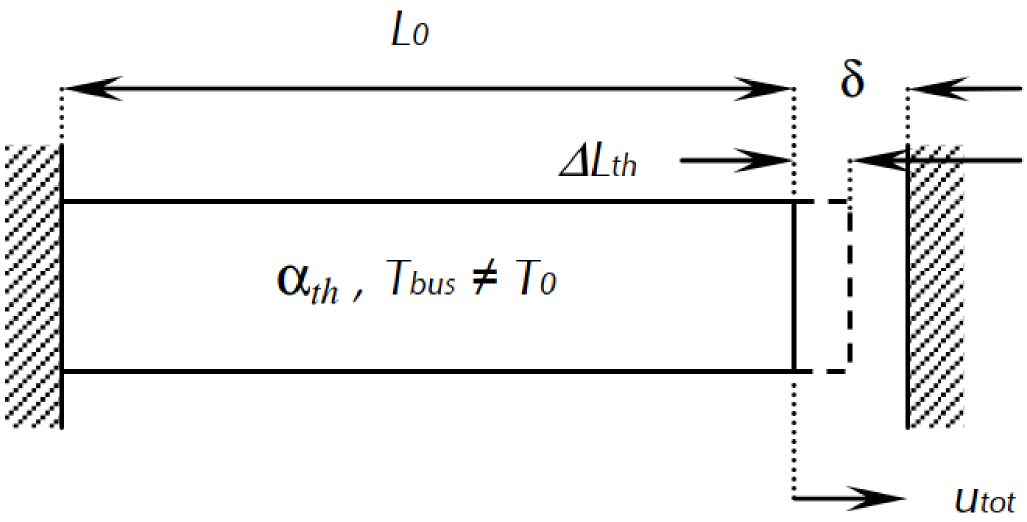
Thermomechanical Problem

- ***Change*** in busbar ***temperature*** leads to ***thermal expansion***:
  - If ***physically restrained***, mechanical ***stresses*** will develop

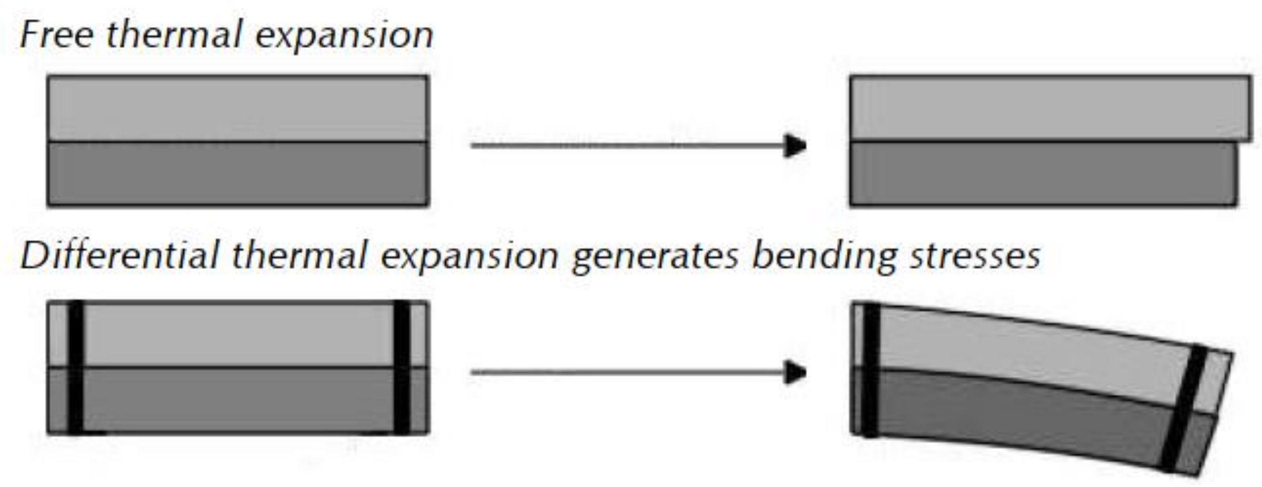
Differential Thermal Expansion



Free busbar thermal expansion limited by stopper



Bimetallic strip problem (differential thermal expansion) *

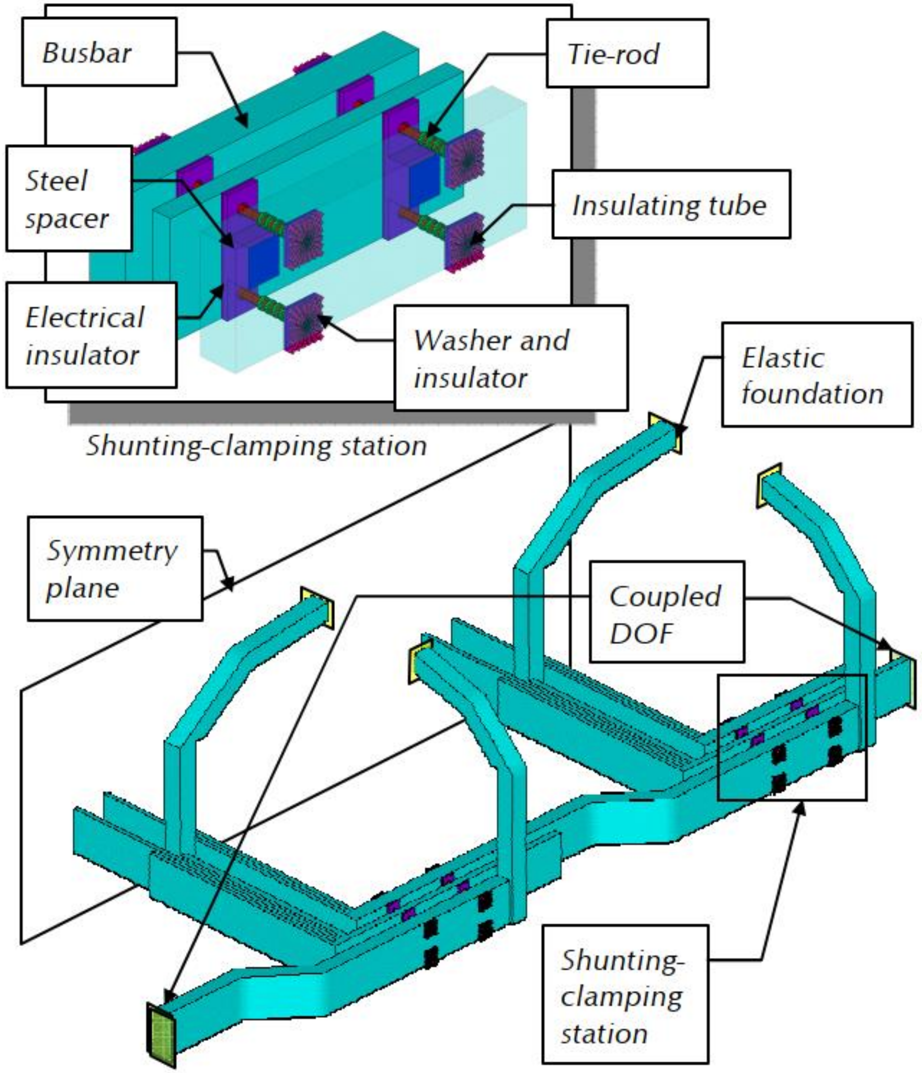


*Most common example is a typical wedging (shunting-clamping) station

Short Busbars

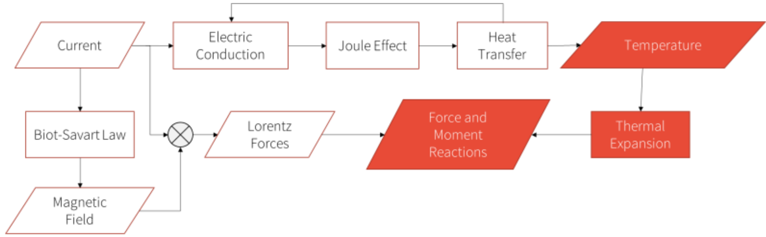
Thermomechanical Problem

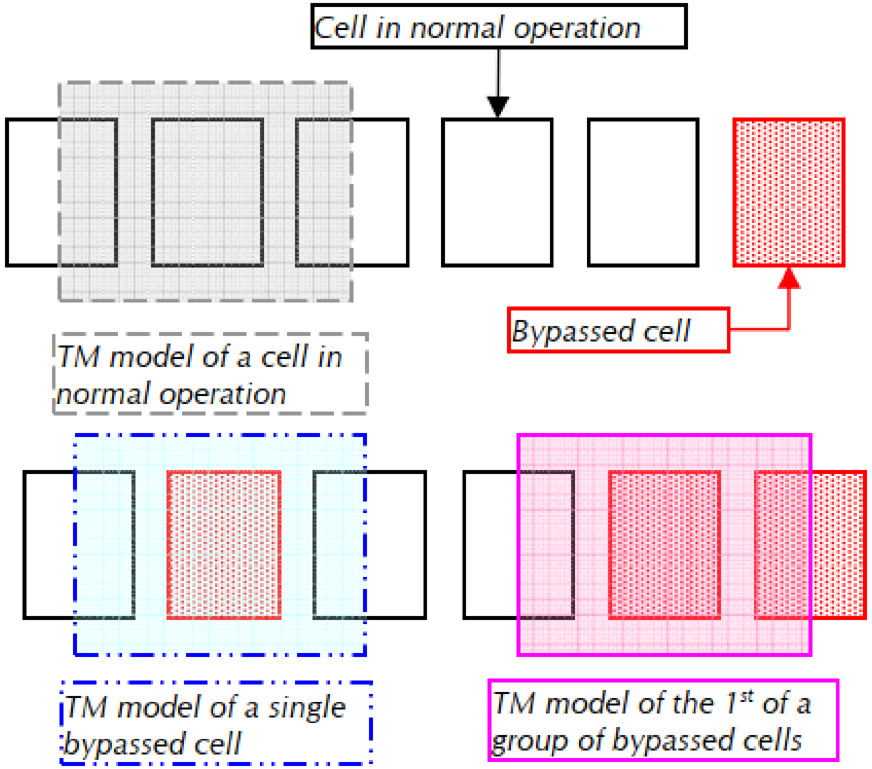
- ***3D Global TM*** **problem for** ***short*** **busbars:**



  - ***2 adjacent*** **pot-to-pot** ***circuits*** **are required to account for** ***mechanical coupling*** **at wedging stations**
  - **Prescribed** ***temperature distribution*** **depends on** ***cell operating mode***

Short Busbars | Global Displacements

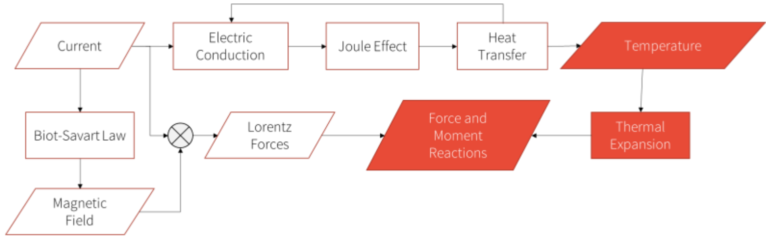




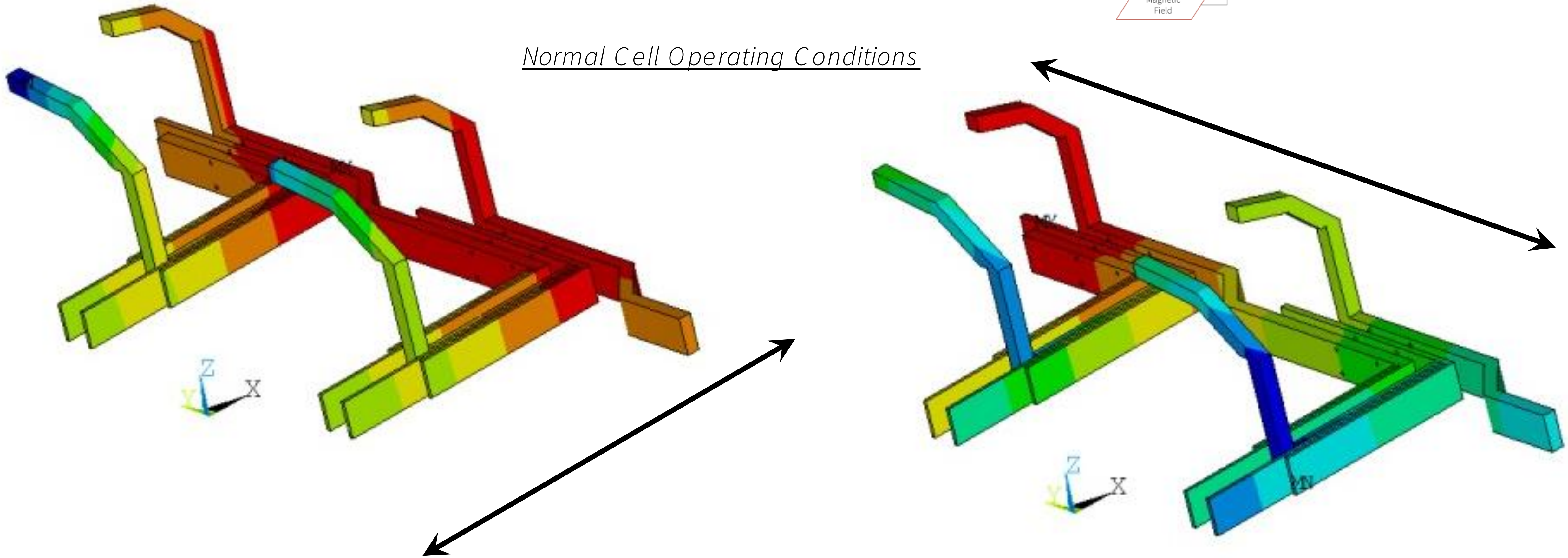
Cell Operating Modes

Thermomechanical Problem

Short Busbars | Applications



- ***Application*** **example:**
  - ***Global*** **pot-to-pot circuit** ***displacements***



Busbar Details

Thermomechanical Problem

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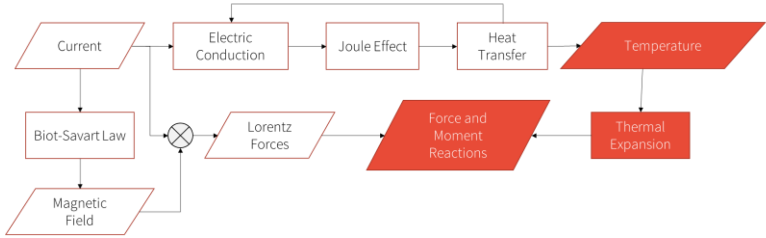
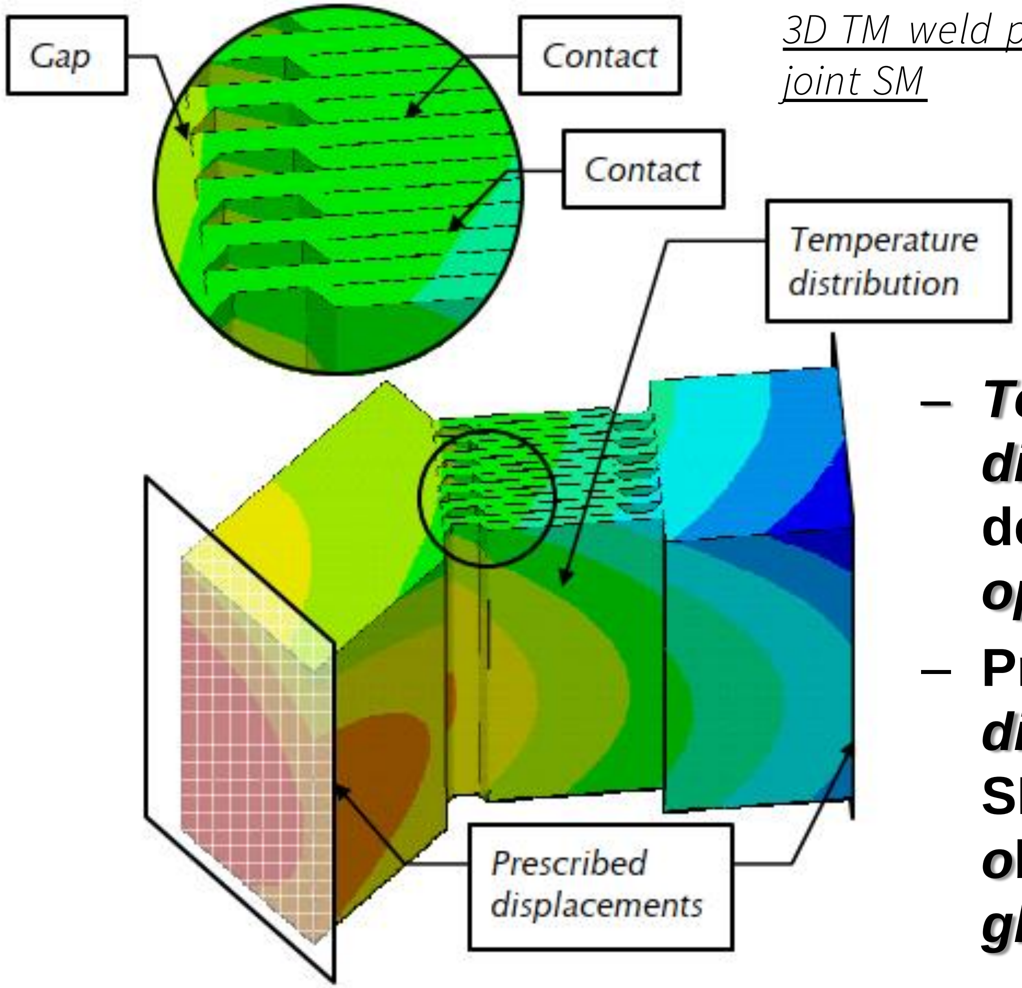
Busbar Details

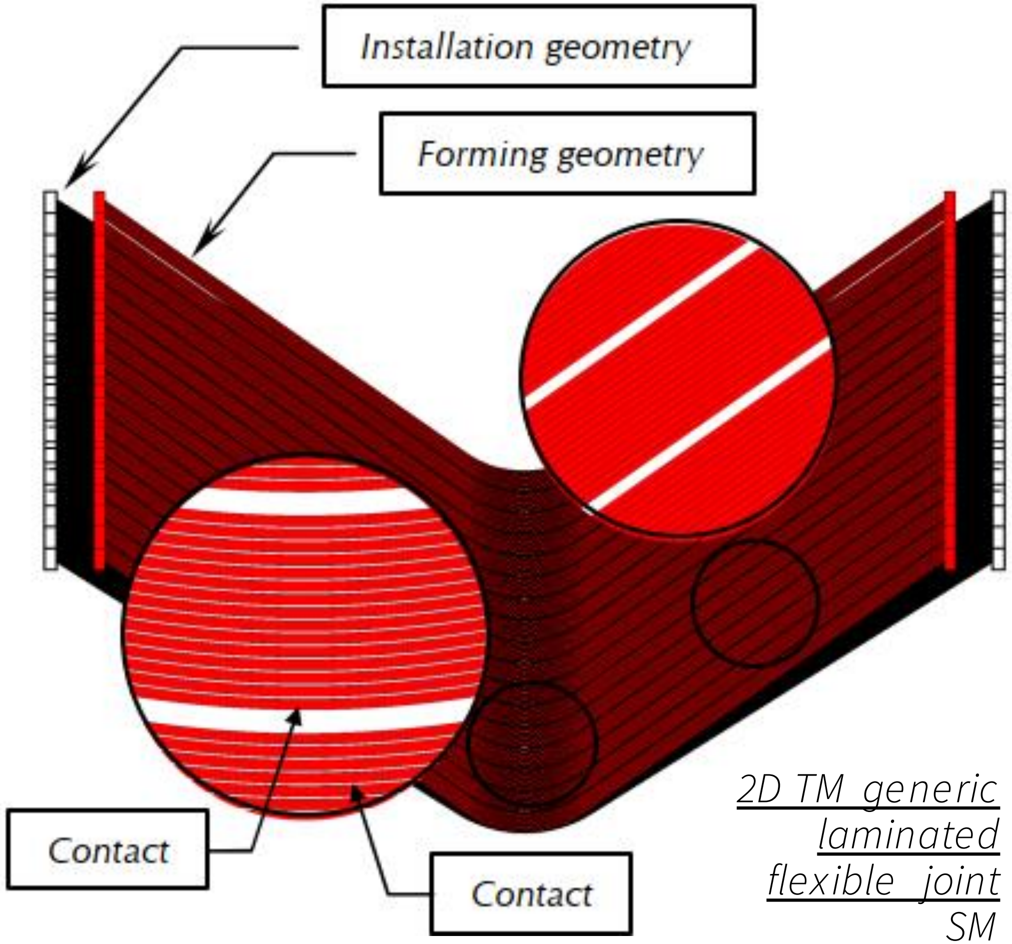


- ***Specialized TM submodels*** (SM) for ***weld plate*** and ***laminated flexible joints*** assessment:



3D TM weld plates joint SM

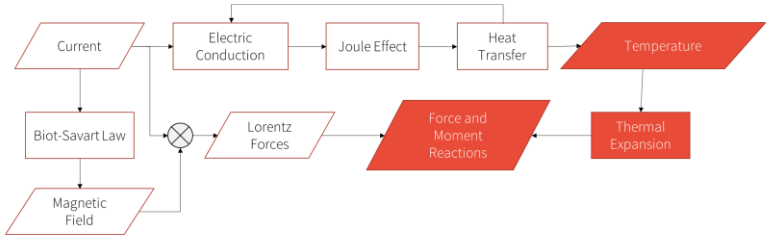
- – ***Temperature distribution*** depends on cell ***operating mode***
- – Prescribed ***displacements*** at SM extremities obtained from ***global TM*** analysis



2D TM generic laminated flexible joint SM

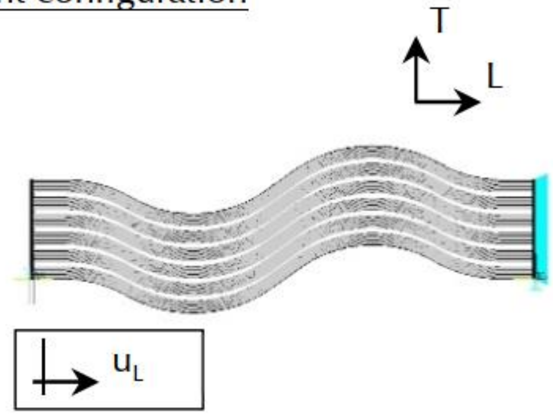
Thermomechanical Problem

Busbar Details | Applications

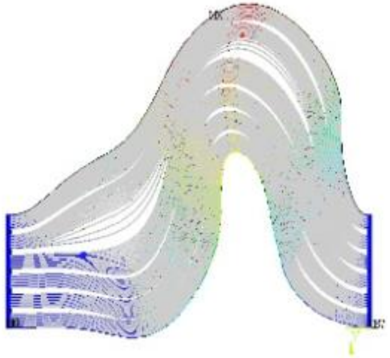


- ***Application*** **examples:**
  - **Laminated *flexible* joint *design* & *performance* assessment**

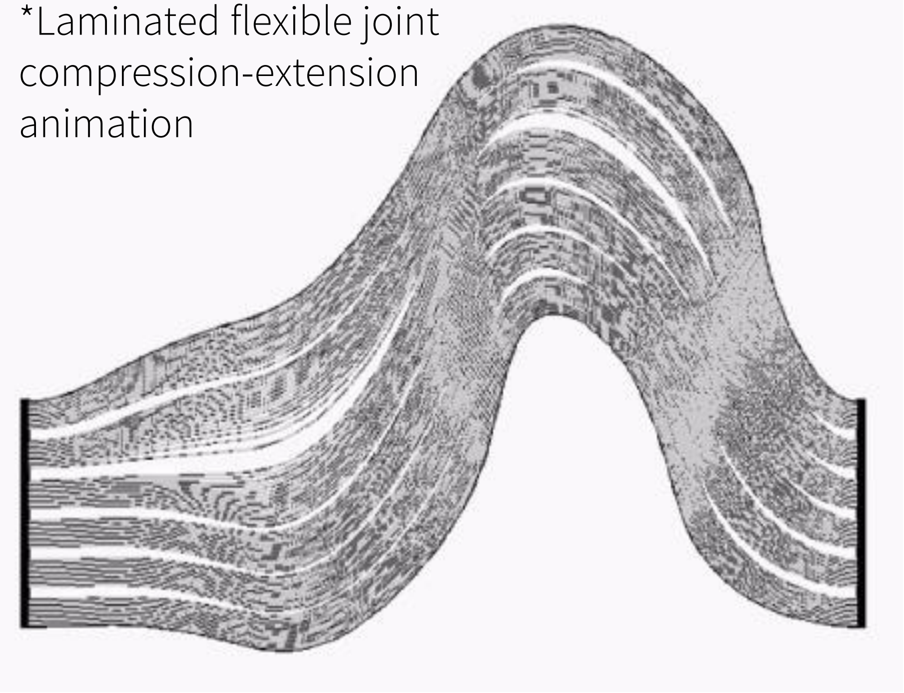
(a) Original joint configuration



Final compression cycle | unloaded deformed shape immediately after u_L = 220 mm (COMP-3)



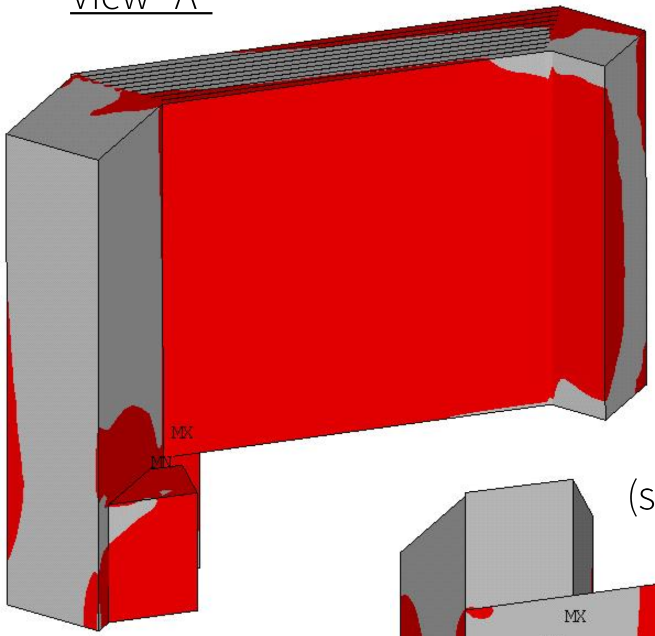
  - **Prediction of *global* joint *buckling* after a series of compression-extension cycles**



Thermomechanical Problem

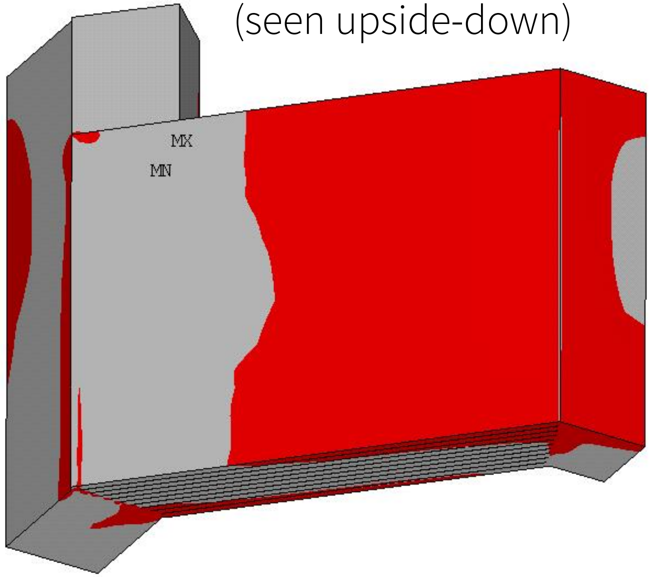
– ***Weld plates*** joint ***design*** & ***performance*** assessment

View "A"

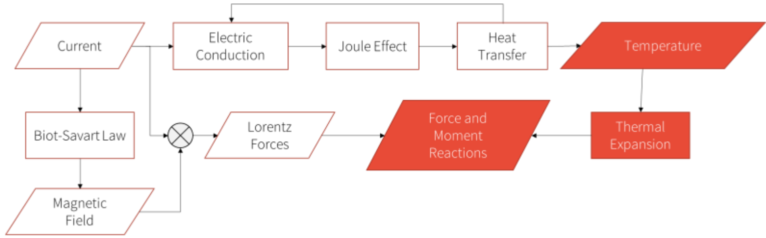


View "B"

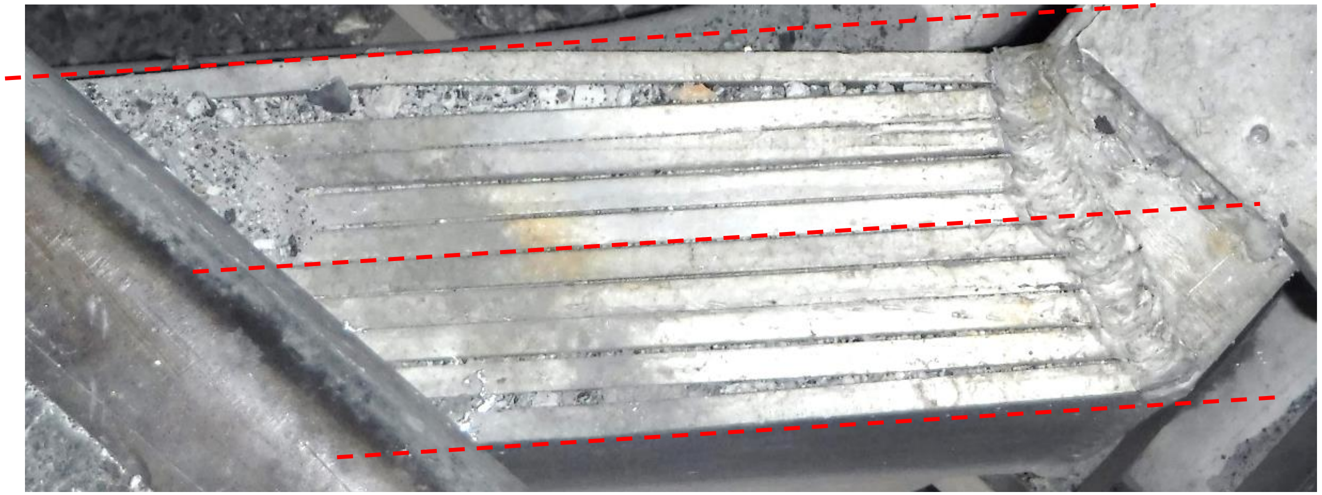
(seen upside-down)



Busbar Details | Applications



– ***Global*** joint ***yielding*** (permanent deformation) under ***multiple bypass*** conditions



Long Busbars

Thermomechanical Problem

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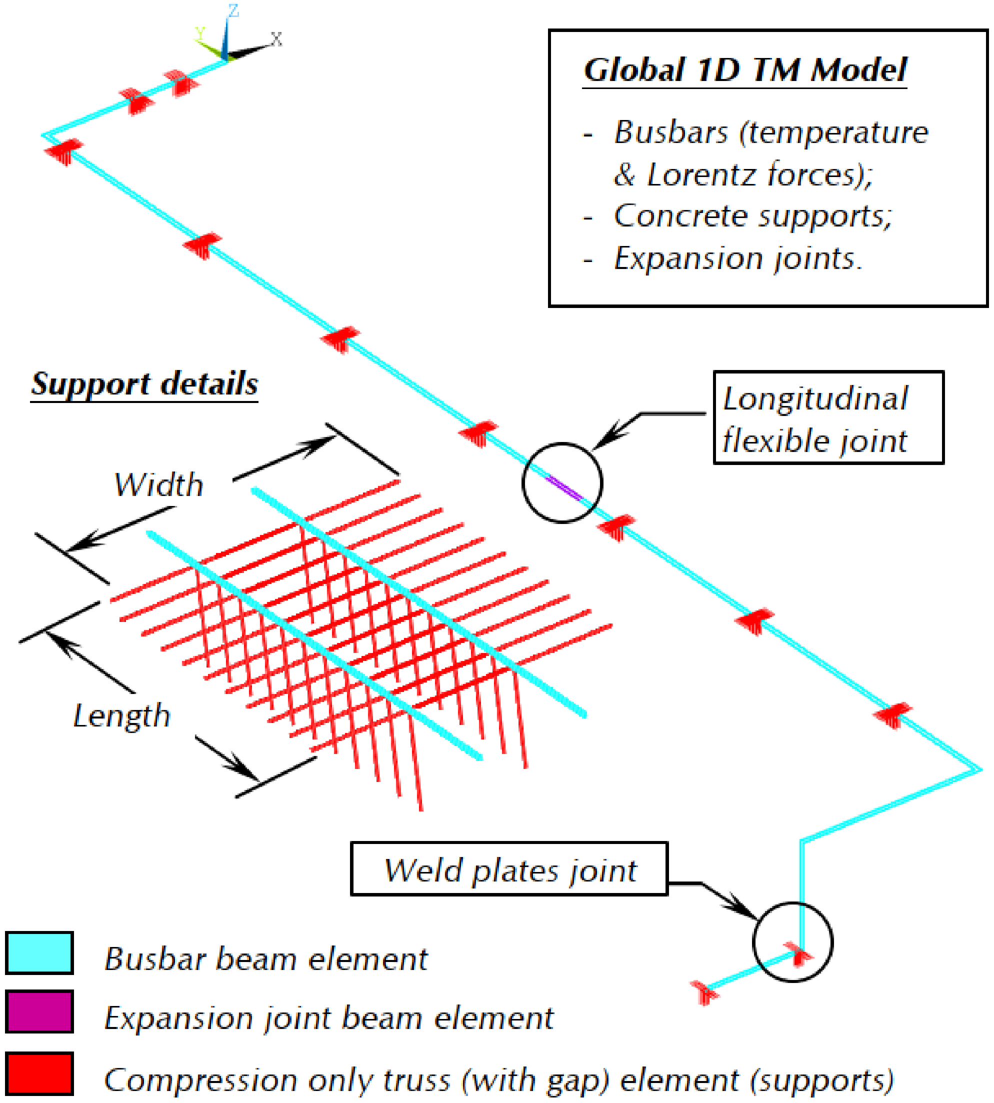
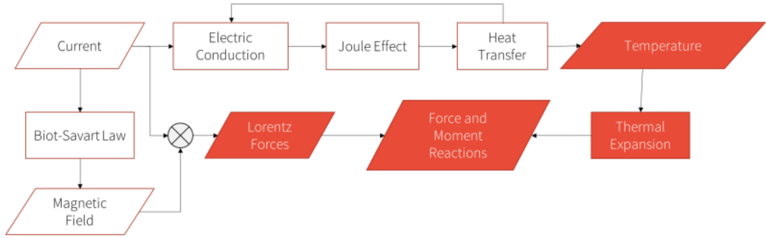
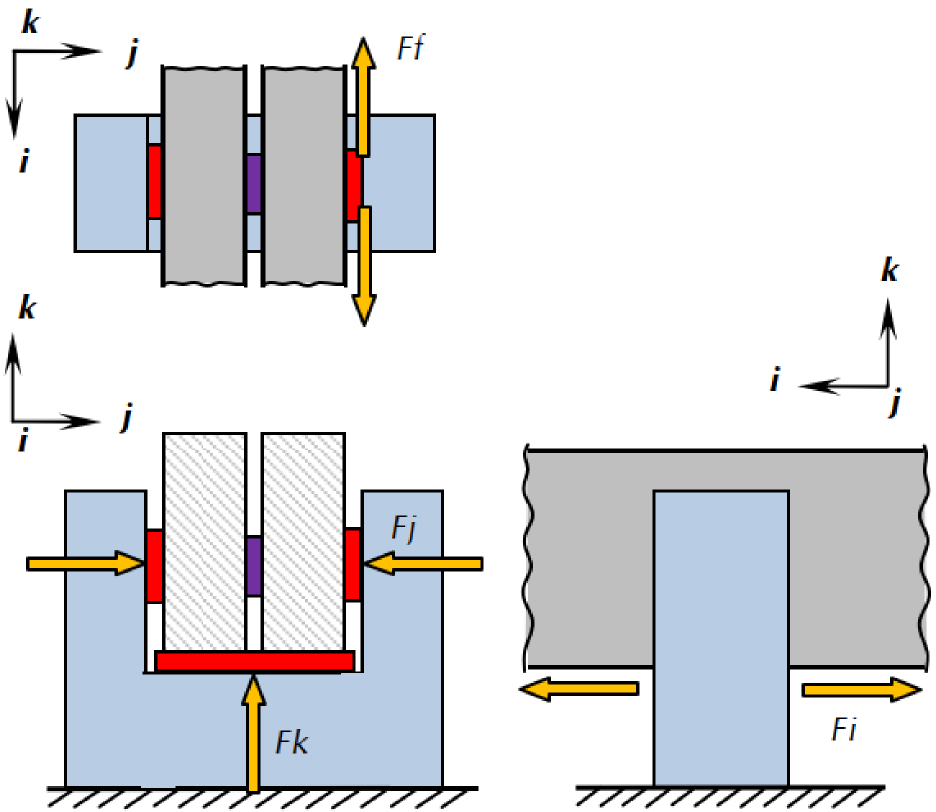
<u>*Long Busbars | Global Displacements*</u>

- ***1D Global TM*** **problem for** ***long*** **busbars:**



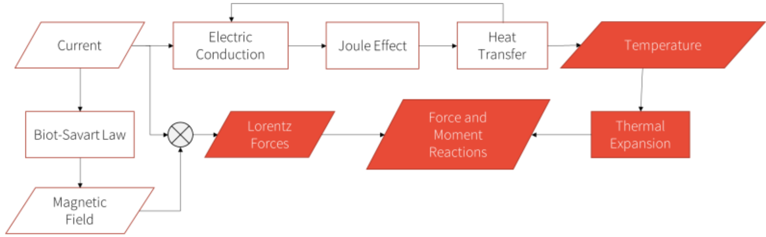


– **Busbar** ***support*** **force & moment** ***reactions*** **caused by** ***Lorentz Forces*** **&** ***temperature distribution***

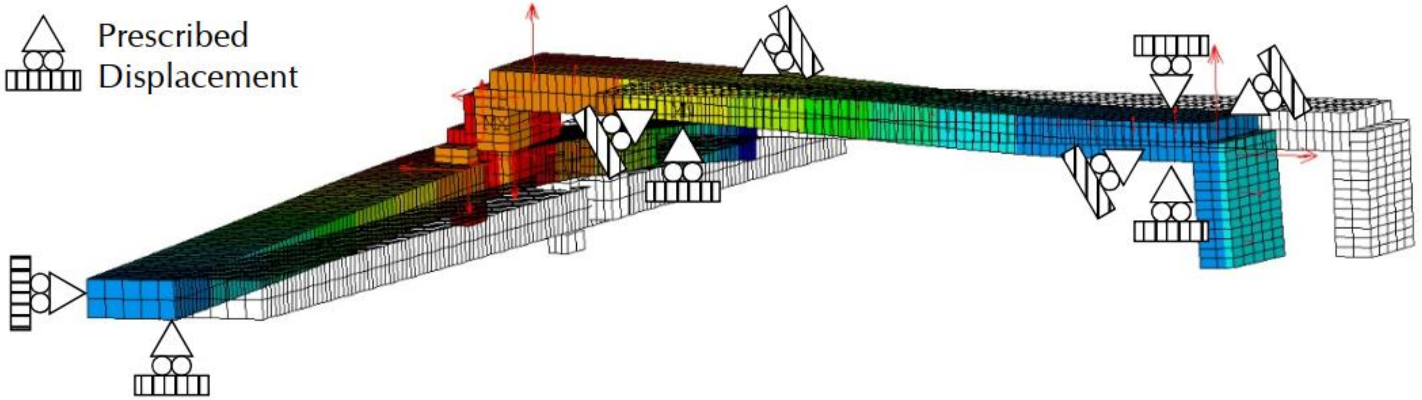


Thermomechanical Problem

Long Busbars | Applications



- ***Application*** **examples:**
  - ***Supports*** **for** ***booster circuit*** **& magnetic** ***compensation loop***



Predicted uplift of magnetic compensation loop segment due to Lorentz forces (short-circuiting condition)

Conclusion

Conclusion

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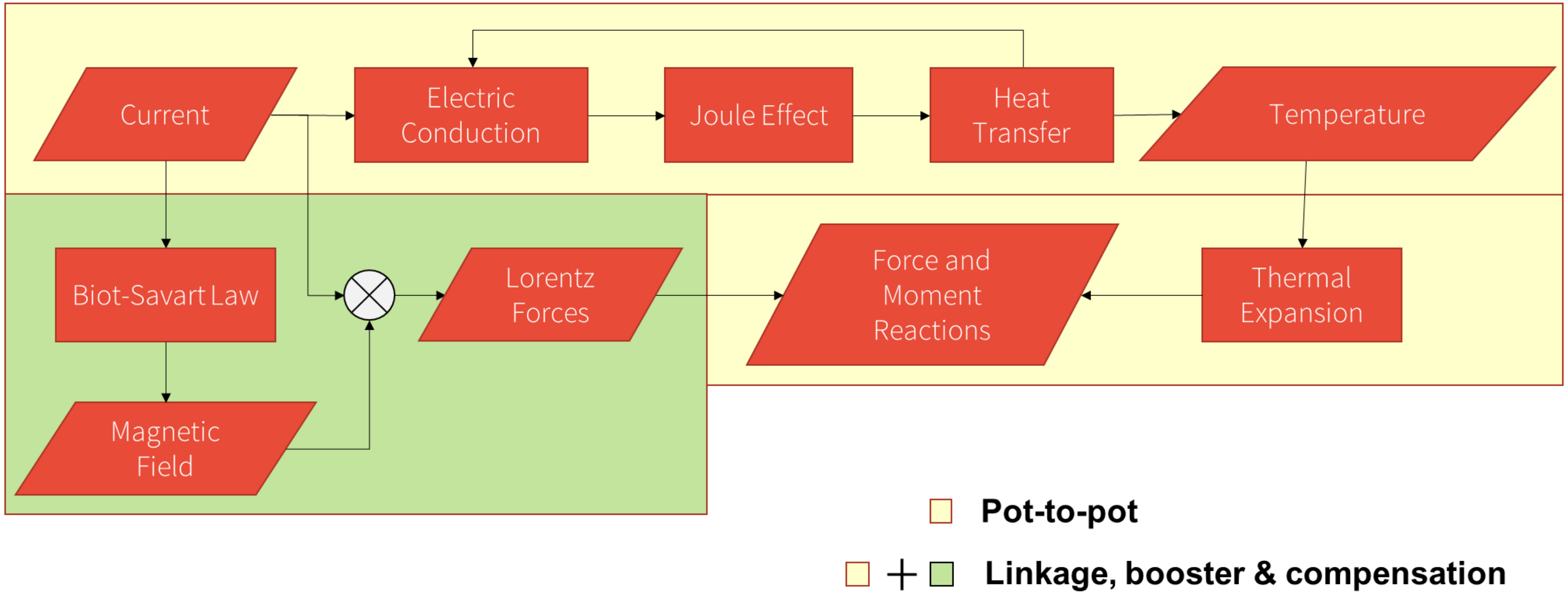
- At the most basic level, ***busbars*** provide ***current for the reduction*** of Al_2O_3 and are ***fundamental*** for the ***electrolysis prosses***:
  - Therefore, their ***reliability*** is ***paramount*** for ensuring ***potline operations***
- ***Several physical phenomena interact*** and must be taken into account when assessing a high-amperage DC busbar system:



Conclusion

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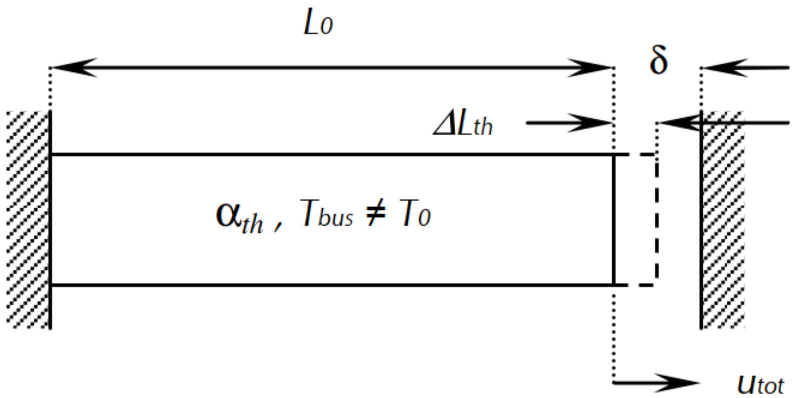
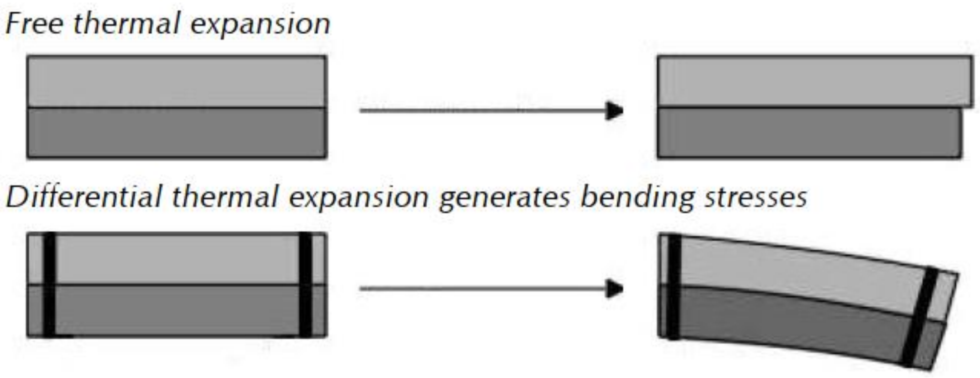
- ***Accurate*** **busbar** ***temperature distribution*** **is of essence in order to** ***predict busbar stresses:***
  - ***Sufficient flexibility*** **must be provided to** ***accommodate differential thermal expansion***





- ***Weldability*** **by** ***electric-arc methods*** **can be** ***assessed*** **by detailed** ***magnetic field distribution*** **computation**
- ***Lorentz Forces*** **must be considered for the** ***design*** **of** ***busbar supports***

Conclusion

- Dedicated ***busbar design group*** at HATCH | Centre of Excellence for Aluminium has developed a ***suite*** of ***numerical tools*** for the ***assessment*** & ***design*** of ***high-amperage DC busbars*** over the past 15 years
- These were ***successfully employed*** to ***safely***:
  - Enable the ***amperage creep*** of potlines (200 – 450 kA range)
  - Install ***booster rectifier circuits*** (200 – 450 kA potlines)
  - Install ***forced cooling*** systems for ***busbars in enclosed spaces*** (350 – 450 kA potlines)
  - Install ***bypass bridges*** for potlines extension (350 – 450 kA range)
  - Install ***bypass bridges*** to ensure ***potline continuity*** in case of a ***major pot-to-pot busbar failure*** (200 – 250 kA potlines)

Conclusion

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- Install ***bypass bridges*** to allow for ***busbar repairs*** by means of readily available ***electric-arc welding*** methods at ***full potline current*** (350 – 450 kA potlines)
- Design busbar details (such as ***weld plate*** & ***laminated flexible joints***) to properly ***accommodate thermal expansion*** (150 – 450 kA potlines)
- Install ***replacement corner risers*** by means of ***reliable bolted connections*** (200 – 250 kA potlines)
- ***Replace*** pot-to-pot & busbar support ***insulating material*** (200 – 400 kA potlines)
- Design a ***major cathode ring modification*** for improved MHD (magnetohydrodynamics) stability (150 – 200 kA potline)

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